

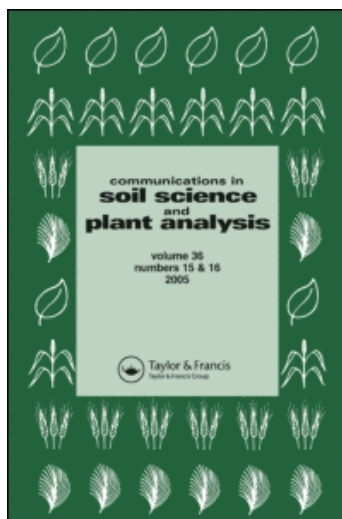
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Effects of Swine Lagoon Effluent and Commercial Fertilizer Applications on Phosphorus Status of an Acid and Alkaline Soil

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Effects of Swine Lagoon Effluent and Commercial Fertilizer Applications on Phosphorus Status of an Acid and Alkaline Soil

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Abstract: Two separate field experiments were conducted to evaluate the effects of swine lagoon effluent relative to inorganic fertilizer at equivalent rates on phosphorus (P) status of an acidic Vaiden (very fine, montmorillonitic, thermic, Aquic Dystrudert)

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and an alkaline Okolona (fine, montmorillonitic, therimic, Typic Chromudert) silty clay soil. In each site, a randomized complete block design with a factorial arrangement of treatments was used. Treatments were replicated four times. Cumulative swine lagoon effluent P application rates for the year 1994 through 1996 were 0, 59, 121, and 175 kg P ha⁻¹ on the Vaiden soil and 0, 72, 148, and 223 kg P ha⁻¹ on the Okolona soil. In each replication, commercial fertilizer P at rates equivalent to swine effluent P application were also included. For both sites, soil P concentration increased with increasing swine effluent and commercial fertilizer P applications. No significant difference in soil P level was observed between two P sources. At high application rate, desorbed P was 1.20 and 0.59 mg P kg⁻¹ in the Okolona and Vaiden soil respectively. In the Vaiden soil, P adsorption approached the maximum for equilibrium P concentration greater than 600 mg L⁻¹. However, Okolona soil displayed a linear adsorption potential with application of swine effluent P. Among P fractions, NH₄Cl-P and HCl-P concentrations increased the most compared to the check in both Okolona and Vaiden soils. Results indicated that P status differs between the soils, but no significant differences in P concentration were obtained between swine lagoon effluent and commercial fertilizer, suggesting that both P sources had similar effect on soil P after 3 years of application.

Keywords: Swine effluent, acid soil, alkaline soil, phosphorus fraction, commercial fertilizer

INTRODUCTION

The potential for phosphorus (P) transport from land irrigated with swine lagoon effluent is a critical concern with confined animal feeding operations. Long-term land application of P as fertilizer or animal wastes can result in elevated levels of soil P (Daniel, Sharpley, and Lemunyon 1998). Conventionally, application of animal waste on cropland is based on the waste determined nitrogen (N) content and plant N needs (Sharpley, Smith, and Bain 1993). Applications of animal waste based on N utilization rates can lead to accumulation of large amounts of P in the soil surface because the N:P ratio in manure is not matched to plant N:P uptake (Sharpley et al. 1994). Farmers are being encouraged to apply animal wastes based on the plant requirement for P as opposed to N particularly on soils with high P contents (Soil Conservation Service 1994). Several reports have shown that accumulation of P in the soil increased with increasing application rates of cattle feedlot manure (Eghbal, Binford, and Baltensperger 1996; Campbell et al. 1986; Sharpley et al. 1984), anaerobically digested poultry manure (Field, Reneau, and Kroontje 1985), poultry litter (Kingery et al. 1994; Mozaffari and Sims 1994; Sims 1991), and swine and poultry manure (Sharpley and Smith 1995; Reddy et al. 1980).

Soil accumulation of P is related to adsorption–desorption characteristics as well as P application rates. Repeated manure applications decreased the P sorption capacity of the surface and subsurface soils, which increases

accumulation of loosely bond P in the soil and increases potential for P movement by runoff (Sharpley, Smith, and Bain 1993; Sims 1991; Reddy et al. 1980; King, Burns, and Westerman 1990). Reddy et al. (1980) reported that increasing application rates to 322 kg P ha^{-1} of swine manure to a Norfolk loamy sand and a Cicil sandy loam soils decreased the subsequent P sorption capacity of the soils and increased P desorption potential at the 0- to 15-cm depth. Phosphorus adsorption by soils amended with various animal manures has been studied (Eghball, Binford, and Baltensperger 1996; Sharpley et al. 1984; Field, Reneau, and Kroontje 1985; Mozaffari and Sims 1996). Sharpley et al. (1984) reported that the effect of feedlot waste on P sorption by the soil was less than fertilizer. Eghball, Binford, and Baltensperger (1996) found that P from feedlot manure moved deeper in the soil than that from chemical fertilizer. Because soils vary in their chemical, physical, and biological properties and vary in their ability to assimilate animal manure nutrients, the effect of swine lagoon effluent relative to commercial fertilizer P at an equivalent rate on P dynamics in soils contrasting in pH is very limited.

Animal wastes contain P fractions that are not susceptible to adsorption by a calcium carbonate layer in the soil and would thus be more likely to leach deeper into the soil than fertilizer P. Identification of P fractions in soils treated with swine lagoon effluent is very important because a close relationship exists between the chemical forms of P in the soils and the amount of P exported from the soils (Vaithiyathan and Correll 1992). Soil P fractionation gives an idea about the soil P-supplying capacity to plants. Biosolid amended Molisol not only increases available P but also decreases P binding affinity by soils and increases P desorption capacity (Sui and Thompson 2000). Sharpley and Smith (1995) reported that the majority of the applied manure P accumulated as weakly bound and plant-available inorganic forms associated with Al and Fe oxides and Ca precipitates. Calcium/Mg-bound P in the soil was loosely bonded by some weak adsorption mechanism and could be leached out under favorable conditions (Nair, Gratez, and Reddy 1995). Chemical fractionation methods have been used to identify various forms of P in soils receiving wastewater (Sommers, Nelson, and Owens 1979), municipal sludge (Chang, Sommerfeldt, and Entz 1991; Taylor et al. 1978), cattle feedlot waste (Sharpley et al. 1984), and fertilizer (Sharpley and Smith 1995). However, P fractionation in soils treated with swine lagoon effluent in Mississippi has not been documented. Anghinony, Baligar, and Wright (1996) reported that soils of the Appalachia region vary widely in their P adsorption-desorption properties. Likewise, soils in Mississippi may also show diversity in their P retention properties. Therefore, soil-specific data on native soil P level, P adsorption-desorption capacities, and soil P fractions are of the utmost importance in developing an agronomically and environmentally sound P management plan. Because soil P status is related to sorption-desorption characteristics as well as soil P fractions (Nair, Gratez, and Reddy 1995), accurate estimates of P sorption capacity and chemical forms of soil P are needed to estimate the application

rate of swine lagoon effluent. Limited data are available on P adsorption, desorption, and fractionation for Mississippi soils when these soil irrigated with swine lagoon effluent for hay-production purposes. Land application has become a widely applied method for treating swine lagoon effluent. It is not always clear which soil–plant systems should be used. This study was conducted to determine if two contrasting soils in pH varied in their ability to assimilate P from treated swine lagoon effluent in comparison with commercial fertilizer P.

MATERIALS AND METHODS

Soil Characteristics and Experimental Design

Studies were conducted for 3 years on two different soils in a commercial swine facility located near Brooksville, Mississippi. Soils were an alkaline Okolona silty clay (fine, montmorillonitic, thermic, Typic Chromudert) and an acid Vaiden silty clay (very fine, montmorillonitic, thermic, Aquic Dystrudert). Initial soil samples were taken from both sites at the depth of 0–15 cm in spring 1994 and analyzed for physical and chemical characteristics (Table 1). Soil pH was measured on a 1:2 soil–water suspension; total carbon was

Table 1. Initial chemical and physical characteristics of Vaiden and Okolona soils used in the study

Parameter	Vaiden	Okolona
pH	5.5	7.3
O.M, g kg ⁻¹	21	26
MSST P, mg kg ^{-1a}	16	23
Ca, mg kg ⁻¹	21	50
Mg, mg kg ⁻¹	160	144
K, mg kg ⁻¹	102	132
Al, g kg ⁻¹	1.7	0.21
CaCO ₃ , g kg ⁻¹	22	480
CEC (mol ₊ kg ⁻¹) ^b	15	24
NH ₄ Cl-P-P, mg kg ⁻¹	0.12	0.18
NaOH-P, mg kg ⁻¹	1.0	0.5
HCl-P, mg kg ⁻¹	8.3	149
Residual- P, mg kg ⁻¹	351	760
Sand, %	11	10
Silt, %	45	40
Clay, %	54	50
Texture	Silty clay	Silty clay

^aMSTP, Mississippi soil test P (Lancaster 1970).
^bCEC, cation exchange capacity.

determined using a Carlo Erba NC 1500 dry combustion analyzer. Organic matter was calculated from total C (TC) ($\% \text{ OM} = \% \text{ TC} \times 1.72/0.58$). The exchangeable cations [sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg)] were determined by extracting soils with 1 M NH_4OAC buffered at pH 7.0 and analyzed using an atomic absorption spectrophotometer. Exchangeable acidity was determined using the BaCl_2 –triethanolamine method (Thomas 1982). The CEC of the soils was calculated by summing exchangeable cations (K, Na, Ca, and Mg) and exchangeable acidity (Thomas 1982; Rhoades 1982). Exchangeable Al was determined by 1 M KCl extraction with titration (Yuan 1959). Texture fractions (sand, silt, and clay) of the soils were determined using the hydrometer method (Day 1965). Calcium carbonate equivalent of the soil samples was determined (Richards 1954). Acid-extractable P was determined using the Mississippi soil test method (Lancaster 1970). Five mL of 0.5 M HCl were added to 5 g of air-dried soil and allowed to sit for 10 min.; then 20 mL of a mixture of glacial acetic acid (CH_3COOH), malic acid [$\text{CH}_2(\text{CO}_2\text{H})_2$], malonic acid [$\text{CH}_2\text{CHOH}(\text{CO}_2\text{H})_2$], ammonium fluoride (NH_4F), and aluminum chloride hexahydrate ($\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$) adjusted to pH 4 was added. The mixture was shaken for 10 min. and filtered, and P was measured colorimetrically (Murphy and Riley 1962).

Annual and total swine effluent and corresponding N, P, and K applications rates defined as check, low, medium, and high are shown in Table 2. At each site, a randomized complete block design with a factorial arrangement of treatments with four replications used. Cumulative swine lagoon effluent P rates for the year 1994 through 1996 were 0, 59, 121, and 175 kg P ha⁻¹ on the Vaiden soil and 0, 72, 148, and 223 kg P ha⁻¹ on the Okolona soil. At each site, commercial fertilizer at the rates equivalent to swine effluent N, P, and K applications were also included. Commercial fertilizer sources were ammonium nitrate (34-0-0), concentrated superphosphate (0-46-0), and muriate of potash (0-0-60). Individual plot dimensions were 3.66 m by 3.66 m with 3.05-m alleys.

Grass Establishment and Maintenance

Hybrid “Alicia” bermudagrass was planted on the Vaiden site by sprigging, at the rate of 63 bushel per ha⁻¹, on 25 May 1995. A manure spreader was used for spreading the clippings, which were disked immediately after spreading and cultipacked. Plots were irrigated with fresh water every day until the bermudagrass was established. Johnsongrass was established on the Okolona site from the previous years. In 1996, for both grasses, Weedmaster (BASF Corporation, Research Triangle Park, NC; active ingredients: dicamba and 2,4-D) was applied during April at the rate of 0.28 kg of dicamba ha⁻¹ and 0.80 kg of 2,4-D ha⁻¹. Winter growth was mowed and removed from all plots in early May in 1995 and 1996 for johnsongrass and in 1996 for bermudagrass.

Table 2. Swine effluent P and fertilizer P rates (kg ha⁻¹) applied to Okolona and Vaiden soils

Rate	1994		1995		1996		Total P	
	Effluent	Fertilizer	Effluent	Fertilizer	Effluent	Fertilizer	Effluent	Fertilizer
Vaiden								
Check	0	0	0	0	0	0	0	0
Low	12	14	17	14	30	28	59	56
Medium	26	28	33	28	62	56	121	112
High	39	42	46	42	90	84	175	168
Okolona								
Check	0	0	0	0	0	0	0	0
Low	12	14	30	28	30	28	72	70
Medium	26	28	60	56	62	56	148	140
High	39	42	90	84	94	84	223	210

Note: In 1994, swine effluent was applied at rates of 0, 2.5, 5, 7.5 cm ha⁻¹. In 1995, the rates were doubled for Okolona site, whereas they were doubled for the Vaiden site in 1996.

Swine Effluent Application, Sampling, and Analysis

The source of swine effluent for irrigation was an anaerobic lagoon at a farrow-to-finish swine operation. To prevent lagoon overflow, swine effluent is usually applied by the swine production facility to adjacent cropland using a center pivot at the rate of 10 cm yr^{-1} from 1 March to 31 October each year. In this study, the target rate was 0, 5, 10, and 15 cm yr^{-1} . In 1994, because of high precipitation during the growing season, only half of the target rate was applied to both Vaiden and Okolona soils. Bermudagrass was established on the Vaiden site in 1995. In 1995, the annual swine lagoon effluent rates stayed the same as in 1994 for Vaiden site because the establishment of bermudagrass would be hindered by the higher rate (15 cm yr^{-1}) of swine effluent application. Therefore, for the Vaiden soil, swine effluent was applied at the rates of 0, 2.5, 5, and 7.5 cm yr^{-1} , whereas the rates were doubled on the Okolona site. In 1996, the annual swine effluent rates were 0, 5, 10, and 15 cm yr^{-1} for both soils. Total swine effluent application rates for the years 1994 through 1996 were 0, 10, 20, and 30 cm yr^{-1} (or equivalent to 0, 59, 112, and 175 kg P ha^{-1}) on the Vaiden soil and 0, 12.5, 25, and 37.5 cm yr^{-1} (or equivalent to 0, 72, 148, and 223 kg P ha^{-1}) on the Okolona soil. Swine effluent was applied in 0.64-cm increments up to 2.5 cm in a given day. Application was repeated until each incremental rate was achieved (i.e., 5, 10, and 15 cm yr^{-1}), at which time application was stopped to allow the forage adequate time to grow for a hay harvest. For each effluent application, 0.64 cm of fresh water was applied to check and fertilized plots to dissolve the commercial fertilizer and to facilitate its incorporation into the soil. A 1500-L water wagon tank was used for delivery of water and swine lagoon effluent. Swine lagoon effluent was applied to the plots using a garden hose attached to the tank with a small pump equipped with a pressure gauge to keep the flow constant. Based on the area of the plot (13.4 m^2), for each application time (0.64 cm), it was calculated that 84 L of swine effluent needed to be applied per plot. To monitor nutrient content of swine effluent, samples were obtained from each tankfull and stored on ice prior to transport to the laboratory. Soluble salts (EC) and pH were determined immediately. Samples were acidified (2 mL of concentrated $\text{H}_2\text{SO}_4\text{ L}^{-1}$ of effluent) and stored at -4°C until analyzed (Greenberg, Clesceri, and Eaton 1992). Unfiltered effluent samples were analyzed for total N using a modified micro-Kjeldahl procedure (Nelson and Sommers 1973). Total inorganic N ($\text{NH}_4 + \text{NO}_3$) of the effluent was analyzed using steam distillation (Bremner and Keeney 1965). Unfiltered swine effluent samples were analyzed using a $\text{H}_2\text{SO}_4\text{-HNO}_3$ acid digestion procedure (Greenberg, Clesceri, and Eaton 1992), and the digest was analyzed for total P using a colorimetric assay (Murphy and Riley 1962). Filtered effluent samples were used for determination of dissolved P at each application time. The average for each parameter is shown in Table 3.

Table 3. Phosphorus and pH content of the swine lagoon effluent used in each year

Parameter	1994	1995	1996	Average
pH	7.8	7.8	7.9	7.8
EC, dSm ⁻¹	0.34	0.39	0.46	0.39
T P, mg L ⁻¹	51	63	61	58
IP, mg L ⁻¹	44	53	52	50
OP, mg L ⁻¹	7	10	9	9
IP/TP, %	86	84	85	86
OP/TP, %	14	16	15	15

Notes: TP = total P, IP = inorganic P, and OP = organic P.

Soil Sampling and Analysis

In the fall 1996, nine soil cores, 5 cm in diameter, were randomly taken from each plot and divided into depths of 0 to 5, 5 to 15, 15 to 30, 30 to 60, and 60 to 90 cm. Samples were composite by depth. Soil samples were air dried, ground to pass a 1-mm sieve, and stored for later analysis. Soil samples were used to evaluate soil P sorption capacity (Fox and Kamprath 1970) after 3 years of swine lagoon effluent applications. Five g of air-dried soil taken at the 0–5-cm depth was placed in a centrifuge tube to which 25 mL of KH₂PO₄ in 0.01 M CaCl₂ at concentrations of 0 to 1500 mg P L⁻¹ (six concentrations) were added. Two drops of toluene were added to minimize microbial activities. The tubes were shaken end over end for a period of 18 h at 25°C and centrifuged at 3000 rpm for 5 min. Sorbed P was calculated as the difference between P added and P in the supernatant at equilibrium. The sorbed P was plotted against the quantity of P at equilibrium for each P addition.

The quantity of desorbed P was determined (Reddy et al. 1980). Duplicate samples (5 g air dry) were shaken with 25 mL of P-free electrolyte solution (0.01 M CaCl₂) to determine the kinetics of soil P depletion. The samples were shaken end over end for 1 h and centrifuged. The supernatant was removed for P analysis and replaced with an equivalent volume of 0.01 M CaCl₂. Five sequential P extractions were performed. At the end of each extraction, P in supernatant was measured colorimetrically (Murphy and Riley 1962) and summed to obtain total quantity of desorbed P.

Sequential extractions were performed with different extractants for P fractions (Nair, Gratez, and Reddy 1995). Labile or readily available P was determined using 5 g of soil extracted with 20 mL of 1 M NH₄Cl shaken for 2 h. Iron/aluminum P (Fe/Al-P) was determined using the remaining soil from the first step extracted with 20 mL of 0.1 M NaOH and shaken for 17 h. The Calcium/magnesium P fraction (Ca/Mg-P) was determined using soil from the second step extracted with 20 mL of 0.5 M HCl and shaken for 24 h. Residual (organic-bond P) was determined by ashing 1 g of previously

extracted soil (Anderson 1976). The general linear model (GLM) procedure in SAS was used to perform an analysis of variance (SAS 1985). Data were analyzed using a simple regression model that included linear and quadratic trends. Analysis of variance using a single-degree-of-freedom comparison was performed to estimate fertilizer equivalence of swine lagoon effluent. Statistical tests were performed at a 0.05 level of significance.

RESULTS AND DISCUSSION

Effects of Swine Lagoon Effluent and Fertilizer Application Rates on Soil Test Phosphorus Levels

The yearly average analysis of swine effluent samples obtained for P concentration is shown in Table 3. Most of the P existed as water-soluble inorganic P (86% of the total P concentration), suggesting that swine effluent is chemically similar to commercial fertilizer.

For both soil types, soil test P increased linearly ($P < 0.01$) with increasing P application rate for both fertilizer and effluent at the 0–5-cm depth (Figures 1 and 2). For the Okolona soil, the net increase in soil test P (difference between final and initial soil test P level) ranged from 2.3 to 51.3 mg kg⁻¹ for application of 70 to 223 kg P ha⁻¹ as effluent. The net increase in soil test P for Vaiden ranged from

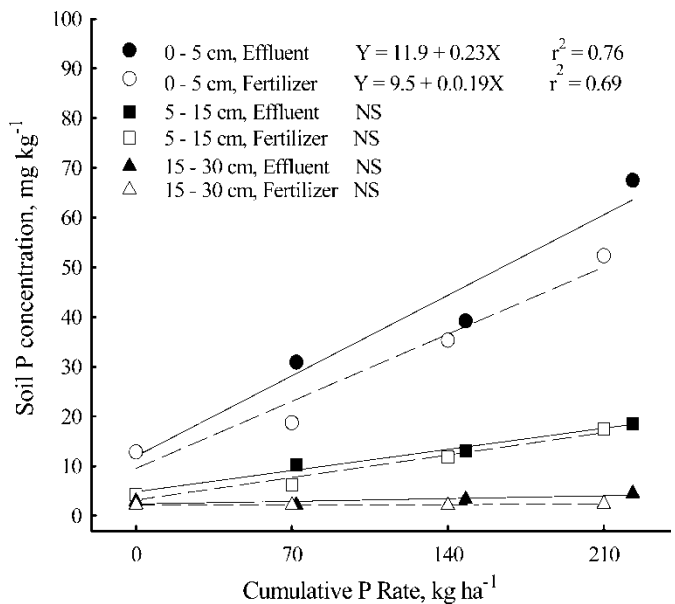


Figure 1. Effects of P sources and rates applied (1994–1996) on soil P concentration at depths of 0–5, 5–15, and 15–30 cm of the Okolona soil, sampled fall of 1996.

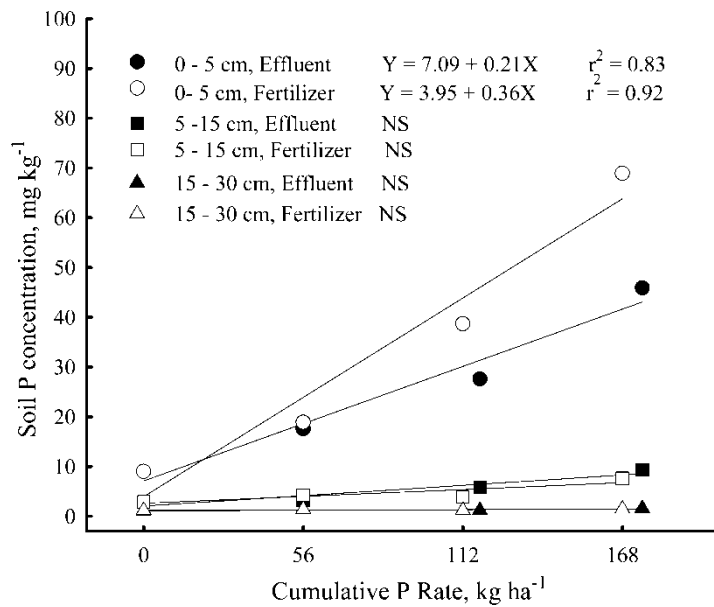


Figure 2. Effects of P sources and rates applied (1994–1996) on soil concentration at depths of 0–5, 5–15, and 15–30 cm of the Vaiden soil, sampled fall of 1996.

6.4 to 57.7 mg kg⁻¹ for application of 59 to 175 kg P ha⁻¹ as effluent. The increase in soil P test level is comparable with other studies (Reddy et al. 1980; Westerman et al. 1987, King, Burns, and Westerman 1990; Sharpley and Smith 1995). Because soil surface is the most interactive zone with rainfall and runoff events, increased P concentration at the surface soil may potential by be transported in runoff water (Sharpley, Smith, and Bain 1993).

For the Vaiden soil, no downward movement of P into the soil profile was obtained from swine lagoon effluent and commercial fertilizer during the 3-yr study. A slight increase in soil P level at the 5–15-cm depth of the Okolona soil is attributed to the cracking nature of this soil, which facilitates the preferential flow to deeper area in the soil. Regardless of P source, calculated from Figures 1 and 2, at the 0–5-cm depth, the quantity of P application required to increase the soil test P by 1 mg kg⁻¹ for Vaiden was lower than Okolona, 5.7 versus 6.3 mg ka⁻¹, respectively. This may be due to greater CaCO₃ content of the Okolona soil (Table 1), which gives it greater P adsorption capacity.

Effects of Swine Lagoon Effluent and Fertilizer Applications Rates on Desorbed Phosphorus

Accumulation of P at the soil surface (0 to 5 cm) indicates the potential for P to be desorbed and transported in runoff events (Pote et al. 1999; Adeli, Varco,

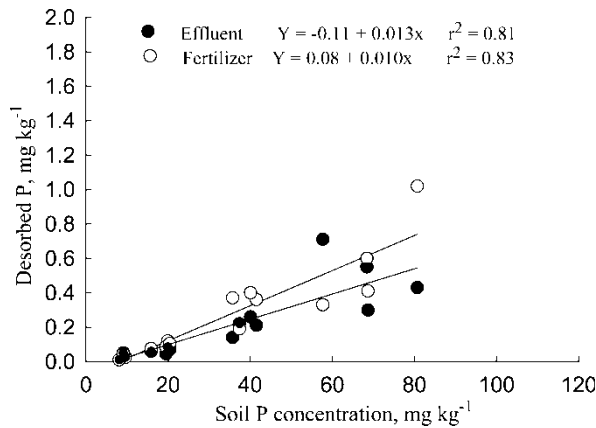


Figure 3. Correlation between soil P concentration and desorbed P at the 0–5-cm depth of the Vaiden soil, sampled fall of 1996.

and Burcham 1995). For both soils sampled in 1996, desorbed P at the 0- to 5-cm depth increased linearly ($P < 0.01$) with increasing levels of soil test P for both fertilizer and effluent treatments (Figures 3 and 4). Based on these results, it is reasonable to assume that soil test P and water-extractable P (desorbed P) would be good indices of the content of labial P forms in

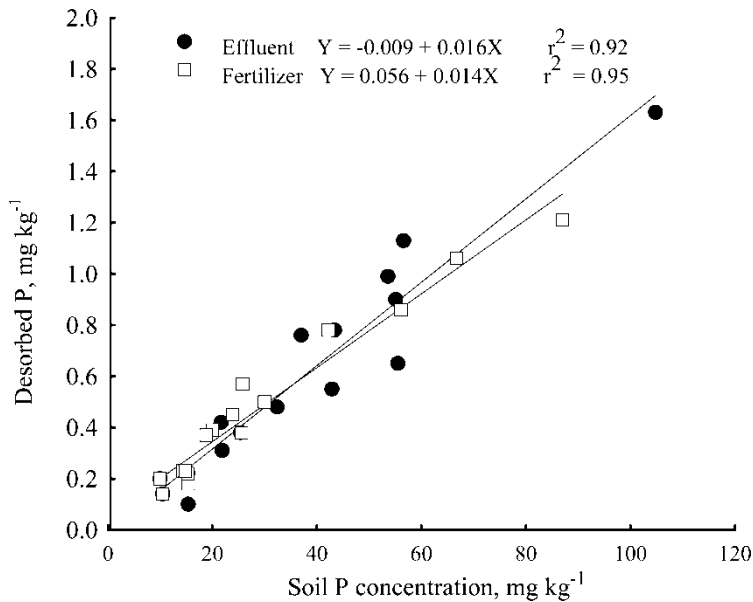


Figure 4. Correlation between soil P concentration and desorbed P at the 0–5-cm depth of the Okolona soil, sampled fall of 1996.

soil and would also be used as a predictive tool to evaluate potential contamination of surface waters from runoff P. Although desorbed P increased linearly with increasing P rates, the magnitude of desorption varied greatly between the soils (Figures 3 and 4). After 3 yr of swine effluent applications, desorbed P at the 0- to 5-cm depth for the high rate was 1.29 mg kg^{-1} in the Okolona soil and 0.60 mg kg^{-1} in the Vaiden soil. Thus, the potential for desorption of P for the Okolona soil is twice that of the Vaiden soil. The greater propensity for P desorption from the Okolona soil is simply due to the fact that the Okolona soil received more P (13 to 48 kg/ha) than the Vaiden soil. Less swine effluent application to the Vaiden site was related to the establishment of bermudagrass on this site in 1995. On the other hand, Raven and Hossner (1994) reported that generally calcareous soils release their P more quickly than acid soils. The greater P desorption for the Okolona soil indicated its potential to supply more P for plant growth than the Vaiden soil.

Effects of Swine Lagoon Effluent on Soil Phosphorus Sorption Capacity

In the Vaiden soil, when sorbed P was plotted against the equilibrium P concentration, P sorption approached a maximum for equilibrium P concentration greater than 600 mg P L^{-1} of solution. Okolona soil displayed a linear sorption potential, and the maximum P sorption was not attained (Figures 5 and 6). Both the alkaline Okolona and the acidic Vaiden soils exhibited a high capacity to adsorb P even at high application rates. The Okolona soil adsorbed more P than the Vaiden soil, which may be attributed to the formation of Ca-P complexes at soil surface due to its high exchangeable Ca^{+2} and the presence of free CaCO_3 . James et al. (1996) reported that because of immobilization and precipitation of a large quantity of P, there is no practical limit of the P retention ability of calcareous soils. The magnitude of soluble P in both soils is low, and soils exhibited a high sorption capacity regardless of P source and application rates.

Effects of Swine Lagoon Effluent and Fertilizer on Soil Phosphorus Fractions

In the Okolona soil, the $\text{NH}_4\text{Cl-P}$ fraction was greater for swine effluent than commercial fertilizer, which indicates that swine effluent P may sustain a greater residual P in the soil and may fully substitute for P fertilizer (Table 4). Regardless of P source and application rate, the $\text{NH}_4\text{Cl-P}$ in the Okolona soil averaged 0.34 mg kg^{-1} , and in the Vaiden soil it averaged 0.16 mg kg^{-1} . The small difference in $\text{NH}_4\text{Cl-P}$ soluble P (0.18 mg kg^{-1}) between two soils could be related to the difference in P application rate, in which the Okolona soil received more P (13 to 48 kg ha^{-1}) than the Vaiden soil (Table 2).

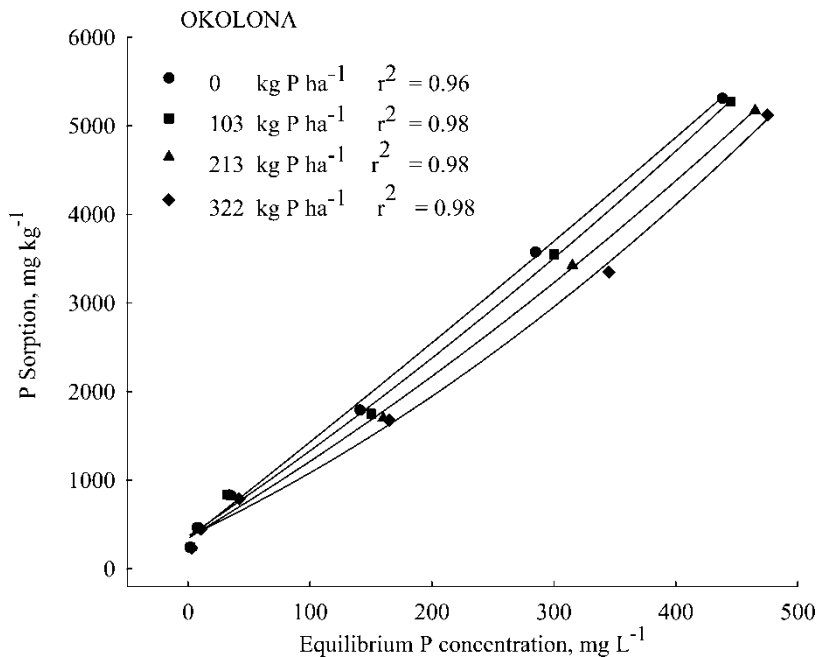


Figure 5. Relationship between P sorption and equilibrium P concentration at the 0–5-cm depth as influenced by P rates applied from swine effluent P (1994–1996).

For both soils, the quantity of NaOH-P (Fe/Al-P) was greater than NH₄Cl-P (easily available P) but much smaller than the HCl-P (Ca/Mg-P) fraction independent of P source (Tables 4 and 5). The NaOH-P increased linearly with increasing rates of P application. No significant difference in NaOH-P fraction was obtained between swine effluent P and commercial fertilizer P in both soils. The concentration of NaOH-P in Okolona soil was 50% less than that found in the Vaiden soil. The greater Fe and Al content of the acidic Vaiden soil may stabilize more P compared to the alkaline Okolona soil and thereby minimize potential for P movement in runoff because NaOH-P (Fe/Al-P) is held more tightly than HCl-P (Ca/Mg-P) (Raven and Hossner 1994). The chemical P forms found in acid soils, such as Fe/Al-bound P, released more slowly than Ca/Mg-bound P in calcareous soils (Raven and Hossner 1994). Thus, the potential for the Vaiden soil to release P and degrade water quality through runoff or leaching is less than the Okolona soil.

The concentration of HCl-P (Ca/Mg-P) fraction at the 0–5-cm depth increased quadratically with increasing commercial fertilizer P application. In contrast, HCl-P (Ca/Mg-P) fraction increased linearly with increasing swine effluent P application (Tables 4 and 5). The concentration of the HCl-P (Ca/Mg-P) fraction was greater for commercial fertilizer P than swine effluent P. Averaged across treatments, the magnitude of HCl-P (Ca/Mg-P)

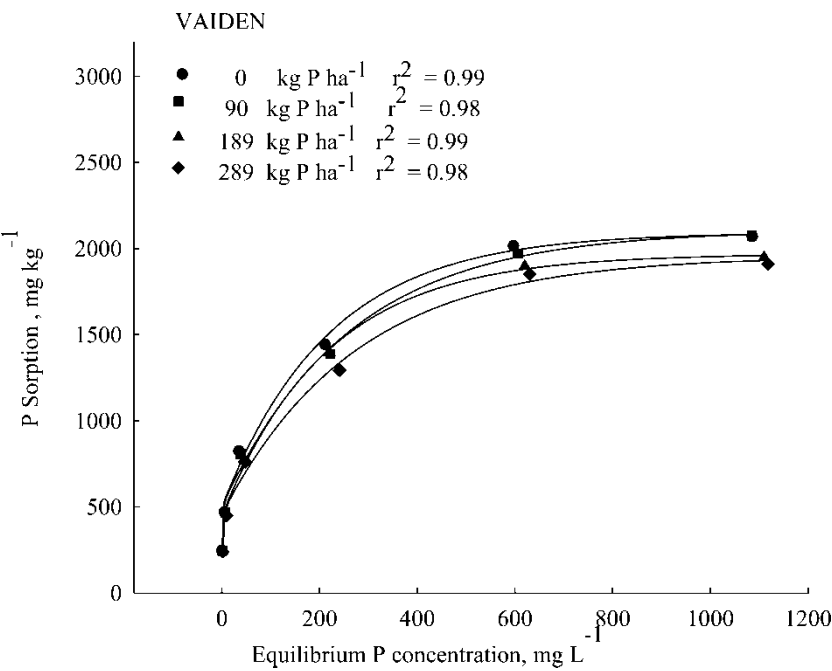


Figure 6. Relationship between P sorption and equilibrium P concentration at the 0–5-cm dept as influenced by P rates applied from swine effluent (1994–1997).

fraction was 217 mg kg⁻¹ for the Okolona soil and 24 mg kg⁻¹ for the Vaiden soil. However, the percentage increase of this fraction compared to the check treatment was greater for the Vaiden soil than the Okolona soil (Table 6). The greater initial soil HCl-P (Ca/Mg-P) fraction of the Okolona soil (149 mg kg⁻¹) than the Vaiden soil (8.3 mg kg⁻¹) likely originated from its greater exchangeable Ca content (Table 1). This is in agreement with the work by Nair, Gratez, and Reddy (1995), who reported that 76% of the total P measured as Ca/Mg-P of an A horizon of soils in abandoned dairy areas is attributed to the high concentration of Ca (72 cmol kg⁻¹) and Mg (47 cmol kg⁻¹). The NaOH-P is chemisorbed P (Williams, Mayers, and Nriagu 1980) and largely reacts with Al and Fe (Iyamuremye, Dick, and Baham 1996). This fraction of P is less related to plant uptake than NH₄Cl-P. Enwezor (1977) reported that the NaOH-P fraction may become mobilized when NH₄Cl-P was depleted from the soil. Williams, Mayers, and Nriagu (1980) also reported that the HCl-P fraction constitutes a stable Ca-bond P, so it would be unlikely to contribute to the eutrophication of water resources. However, it would be mobilized to a labile fraction when the latter is depleted. Calcium-bonded P minerals and amorphous Fe/Al-P can be important sinks for the added/mineralized P in the agricultural soils (Simard et al. 1995). Increases in the Ca-bonded P fraction might result in

Table 4. Effects of P sources and cumulative rates applied (1994 through 1996) on P fractions of the 0–5-cm depth of the Okolona soil, sampled fall of 1996

P source	P rate (kg ha ⁻¹)	Analysis	NH ₄ Cl-P (mg kg ⁻¹)	NaOH-P (mg kg ⁻¹)	HCl-P (mg kg ⁻¹)	Residual-P (mg kg ⁻¹)
Check	0		0.14	0.5	154	780
Fertilizer	70		0.17	0.9	269	848
	140		0.28	0.9	241	902
	210		0.36	1.4	177	960
Effluent	72		0.26	0.9	160	825
	148		0.28	1.1	219	905
	223		0.68	2.4	236	1015
		Check vs. others	**	**	**	**
		Fertilizer vs. effluent	NS	NS	*	NS
		Fertilizer × effluent	NS	NS	NS	NS
		Fertilizer linear	**	**	**	*
		Fertilizer quadratic	NS	NS	*	NS
		Effluent linear	**	**	*	**
		Effluent quadratic	NS	NS	NS	NS

Notes: **significant at 0.01 probability level, *significant at 0.05 probability level, NS not significant.

Table 5. Effects of P sources and P cumulative rates applied (1994 through 1996) on P fractions of the 0–5-cm depth of the Vaiden soil, sampled fall of 1996

P source	P rate (kg ha ⁻¹)	Analysis	NH ₄ Cl-P (mg kg ⁻¹)	NaOH-P (mg kg ⁻¹)	HCl-P (mg kg ⁻¹)	Residual-P (mg kg ⁻¹)
Check Fertilizer	0		0.13	0.7	5.4	332
	56		0.14	1.5	12.8	319
	112		0.18	2.3	26.6	395
	168		0.16	3.3	48.4	463
Effluent	59		0.15	1.4	11.9	385
	121		0.17	2.1	17.8	408
	175		0.19	3.2	29.1	345
		Check vs. others	*	**	**	*
		Fertilizer vs. effluent	NS	NS	*	NS
		Fertilizer × effluent	NS	NS	NS	NS
		Fertilizer linear	*	**	**	**
		Fertilizer quadratic	NS	NS	*	NS
		Effluent linear	**	**	**	NS
		Effluent quadratic	NS	NS	NS	NS

Notes: **significant at 0.01 probability level, *significant at 0.05 probability level, NS not significant.

Table 6. Percentage increase in soil P fractions compared to the check treatment at high swine effluent application rate at the 0–5-cm depth sampled fall of 1996

P fraction	Okolona	Vaiden
NH ₄ Cl	58	15
NaOH	54	69
HCl	39	78
Residual	15	14
SED ^a	3.1	4.2

^aStandard error of difference.

precipitation of mineralized/added P, which is environmentally advantageous (Condrón and Goh 1989). Readily available P (NH₄Cl-P) had the greatest percentage increase (net increase) as compared to the check treatment among all the P fractions in the Okolona soil (Table 6). The magnitude of residual P was the largest fraction in both soils (Tables 4 and 5), indicating the importance of crop residue and soil microorganisms in P cycling and reactions of swine effluent derived P with humic substances (Leinweber, Haumaier, and Zech 1997). For the Okolona soil, residual P fraction increased with increasing swine effluent P application (Table 4). For the Vaiden soil, residual P was not affected by swine effluent application. However, for both soils and among all P fractions, it seems that the residual fraction of P had the lowest percentage increase compared to the check treatments (net increase). Depending on soil pH, residual P (organic bound P) could become available for plant uptake through mineralization as well as being converted into stable organo-metal complexes (Nair, Gratez, and Reddy 1995). For the Okolona soil at the highest swine effluent application rate, the sequential fractionation of P showed a net increase in the order of NH₄Cl-P > NaOH-P > HCl-P > residual P (Table 6). For the Vaiden soil, the sequential fractionation of P was in the order of HCl-P > NaOH-P > NH₄Cl-P > residual P. This indicates that Okolona soil may have the potential to supply more P for plant growth (Table 6).

CONCLUSIONS

For both soil types, the quantity of soil test P linearly increased with increasing swine effluent and commercial fertilizer applications. For the Vaiden soil, P adsorption approached the maximum, showing no further increase with increasing equilibrium P concentration greater than 600 mg P L⁻¹, whereas Okolona soil did not reach the maximum P adsorption capacity and displayed a linear sorption potential. For the Okolona soil, the percentage

increase in the $\text{NH}_4\text{Cl-P}$ fraction was greatest compared to the other P fractions, whereas for the Vaiden soil the greatest percentage increase belonged to the HCl-P fraction. Except for the HCl-P fraction, no significant difference in soil P fractions was observed between P sources in both soil types. Thus, the fate of P from commercial fertilizer application appears to be a useful tool for predicting P dynamics for finding best management practices in animal waste disposal.

REFERENCES

- Adeli, A., Varco, J.J., and Burcham, T. (1995) Swine lagoon effluent and N-P-K fertilizer effects on yield, nutrient removal and residual soil levels of N and P. J. B. Daniel (ed.) In 25th Proceedings of the Mississippi Water Resources Conference, Water Resources Research Institute: Jackson, Mississippi; April 2–3, 1995, p. 213–228.
- Anderson, J.M. (1976) An ignition method for determination of total phosphorus in lake sediments. *Water Research*, 10: 329–331.
- Anghinoni, I., Baligar, V.C., and Wright, R.J. (1996) Phosphorus sorption isotherm characteristics and availability parameters of Appalachian acidic soils. *Communications in Soil Science and Plant Analysis*, 27 (9–10): 2033–2048.
- Bremner, J.M. and Keeney, D.R. (1965) Steam-distillation methods for determination of ammonium, nitrate and nitrite. *Analytica Chimica Acta*, 32: 31–36.
- Campbell, C.A., Schnitzer, M., Stewart, J.W.B., Biederbeck, V.O., and Selles, F. (1986) Effect of manure and P fertilizer on properties of a black chernozem in southern Saskatchewan. *Canadian Journal of Soil Science*, 66: 601–603.
- Chang, C., Sommerfeldt, T.G., and Entz, T. (1991) Soil chemistry after eleven applications of cattle feedlot manure. *Journal of Environmental Quality*, 20: 475–480.
- Condon, L.M. and Goh, K.M. (1989) Effects of long-term phosphatic fertilizer applications on amounts and forms of phosphorus in soils under irrigated pasture in New Zealand. *Journal of Soil Science*, 40: 383–395.
- Daniel, T.C., Sharpley, A.N., and Lemunyon, J.L. (1998) Agricultural phosphorus and eutrophication: A symposium overview. *Journal of Environmental Quality*, 27: 251–257.
- Day, P.R. (1965) Particle fractionation and particle size analysis. In *Methods of Soil Analysis, Part 1*; Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E. and Clark, F.E. (eds.); Agronomy Monograph 9 American Society of Agronomy: Madison, Wisconsin, 82–84.
- Eghball, B., Binford, G.D., and Baltensperger, D.D. (1996) Phosphorus movement and adsorption in a soil receiving long-term manure and fertilizer application. *Journal of Environmental Quality*, 25: 1339–1343.
- Enwezor, W.O. (1977) Soil testing for phosphorus in some Nigerian soils, I: Comparison of methods of determining available phosphorus in soils of south-eastern Nigeria. *Soil Science*, 123: 48–53.
- Field, J.A., Reneau, R.B., and Kroontje, W. (1985) Effects of anaerobically digested poultry manure on soil phosphorus adsorption and extractability. *Journal of Environmental Quality*, 14 (1): 105–107.
- Fox, R.L. and Kamprath, E.J. (1970) Phosphorus sorption isotherms for evaluating the phosphate requirements of soils. *Soil Science Society of America Journal*, 34: 902–906.

- Greenberg, A.E., Clesceri, L.S., and Eaton, A.D. (1992) *Standard Methods for the Examination of and Wastewater*; 18th ed.; APHA/WEF/AWWA, American Public Health Association: Washington, D.C.
- Iyamuremye, F., Dick, R.P., and Baham, J. (1996) Organic amendments and phosphorus dynamics, II: Distribution of soil phosphorus fractions. *Soil Science*, 161: 436–443.
- James, D.W., Amacher, J.K., Anderson, G.L., and Huber, D.A. (1996) Phosphorus mobility in calcareous soils under heavy manuring. *Journal of Environmental Quality*, 25: 770–775.
- King, L.D., Burns, J.C., and Westerman, P.W. (1990) Long-term swine lagoon effluent applications on “Coastal” bermudagrass, II: Effect on nutrient accumulation in soil. *Journal of Environmental Quality*, 19: 756–760.
- Kingery, W.L., Wood, C.W., Delaney, D.P., Williams, J.C., and Mullins, G.L. (1994) Impact of long-term land application of broiler litter on environmentally related soil properties. *Journal of Environmental Quality*, 23: 139–147.
- Lancaster, J.D. (1970) *Determination of Available P and K in Soils*; Mississippi Agricultural Forestry Experimental Station: Mississippi, Mississippi State.
- Leinweber, P., Haumaier, L., and Zech, W. (1997) Sequential extractions and ^{31}P -NMR spectroscopy of P forms in animal manures, soils and particle-size separates from a densely populated livestock area in northwest Germany. *Biol-fertil-soils*, 25 (1): 89–94.
- Mozaffari, M. and Sims, J.T. (1994) Phosphorus availability and sorption in an Atlantic Coastal Plain watershed dominated by animal-based agriculture. *Soil Science*, 157 (2): 97–106.
- Mozaffari, M. and Sims, J.T. (1996) Phosphorus transformations in poultry litter-amended soils of the Atlantic Coastal Plain. *Journal of Environmental Quality*, 25: 1357–1365.
- Murphy, J. and Riley, J.P. (1962) A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27: 31–36.
- Nair, V.D., Gratez, D.A., and Reddy, K.R. (1995) Dairy manure influence on phosphorus retention capacities of Spodosols. *Journal of Environmental Quality*, 27: 522–527.
- Nelson, D.W. and Sommers, L.E. (1973) Determination of total nitrogen in plant material. *Agronomy Journal*, 65: 109–111.
- Pote, D.H., Daniel, T.C., Nichols, D.J., Sharpley, A.N., Moore, P.A., Miller, D.M., and Edwards, D.R. (1999) Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. *Journal of Environmental Quality*, 28: 170–175.
- Raven, K.P. and Hossner, L.R. (1994) Soil phosphorus desorption kinetics and its relationship with plant growth. *Soil Science Society of America Journal*, 58: 416–423.
- Reddy, K.R., Overcash, M.R., Khaleel, R., and Westerman, P.W. (1980) Phosphorus adsorption–desorption characteristics of two soils utilized for disposal of animal wastes. *Journal of Environmental Quality*, 9: 86–92.
- Rhoades, J.D. (1982) Cation exchange capacity. In *Methods of Soil Analysis, Part 2*; Page, A.L., Miller, R.H. and Keeney, D.R. (eds.); American Society of Agronomy Soil Science Society of America: Madison, Wisconsin, 149–157.
- Richards, L.A. (ed.). (1954) *Diagnosis and Improvement of Saline and Alkali Soils*; U.S. Salinity Laboratory, U.S. Government Printing Office: Washington, D.C., 106USDA Handbook 60.
- SAS Institute. (1995) *SAS User's Guide*; SAS Institute: Cary, North Carolina.

- Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C., and Reddy, K.R. (1994) Managing agricultural phosphorus for protection of surface waters: Issues and options. *Journal of Environmental Quality*, 23: 437–451.
- Sharpley, A.N. and Smith, S.J. (1995) Nitrogen and phosphorus forms in soils receiving manure. *Soil Science*, 159 (4): 253–258.
- Sharpley, A.N., Smith, S.J., and Bain, W.R. (1993) Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. *Soil Science Society of America Journal*, 57: 1131–1137.
- Sharpley, A.N., Smith, S.J., Stewart, B.A., and Mathers, A.C. (1984) Forms of Phosphorus in soil receiving cattle feedlot waste. *Journal of Environmental Quality*, 13 (2): 211–214.
- Simard, R.R., Cluis, D., Gangbazo, G., and Beauchemin, S. (1995) Phosphorus status of forest and agricultural soils from a watershed of high animal density. *Journal of Environmental Quality*, 24: 1010–1017.
- Sims, J.T. (1991) Environmental management of phosphorus in agricultural and municipal wastes. In *Future Directions for Agricultural Phosphorus Research*; Sikora, F.J. (ed.); Muscle Shoals Tennessee Valley Authority National Fertilizer Environmental Research Center: Alabama, 16–29.
- Soil Conservation Service. (1994) Waste utilization standard and specification. SCS Technical Practice Code 633, USDA-Soil Conservation Services: Stillwater, Oklahoma.
- Sommers, L.E., Nelson, D.W., and Owens, L.B. (1979) Status of inorganic phosphorus in soils irrigated with municipal wastewater. *Soil Science*, 30: 340–350.
- Sui, Y. and Thompson, M.L. (2000) Phosphorus sorption, desorption, and buffering capacity in biosolid-amended Molisol. *Soil Science Society of America Journal*, 64: 164–169.
- Taylor, J.M., Sikora, F.J., Tester, C.F., and Parr, J.F. (1978) Decomposition of sewage sludge compost in soil, II: Phosphorus and sulfur transformations. *Journal of Environmental Quality*, 7: 119–123.
- Thomas, G.W. (1982) Exchangeable cations. In *Methods of Soil Analysis, Part 2*; Page, A.L., Miller, R.H. and Keeney, D.R. (eds.); American Society of Agronomy; Soil Science Society of America: Madison, Wisconsin, 159–165.
- Vaithyanathan, P. and Correll, D.L. (1992) The Rhode River Watershed: Phosphorus distribution and export in forest and agricultural soils. *Journal of Environmental Quality*, 21: 280–288.
- Westerman, P.W., King, L.D., Burns, J.C., Cummings, G.A., and Overcash, M.R. (1987) Swine lagoon effluent applied to a temperate forage mixture, II: Rainfall runoff and soil chemical properties. *Journal of Environmental Quality*, 16: 106–112.
- Williams, J.D.H., Mayers, T., and Nriagu, J.O. (1980) Extractability of phosphorus from phosphate minerals common in soils and sediments. *Soil Science Society of America Journal*, 44: 462–465.
- Yuan, T.L. (1959) Determination of exchangeable aluminum in soils by a titration method. *Soil Science*, 88: 164–167.